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Short Communication

A Measure of Acoustic Noise Generated From Transcranial Magnetic Stimulation Coils

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ABSTRACT

The intensity of sound emanating from the discharge of magnetic coils used in repetitive transcranial magnetic stimulation (rTMS) can potentially cause acoustic trauma. Per Occupational Safety and Health Administration (OSHA) standards for safety of noise exposure, hearing protection is recommended beyond restricted levels of noise and time limits. We measured the sound pressure levels (SPLs) from four rTMS coils with the goal of assessing if the acoustic artifact levels are of sufficient amplitude to warrant protection from acoustic trauma per OSHA standards. We studied the SPLs at two frequencies (5 and 10 Hz), three machine outputs (MO) (60, 80 and 100%), and two distances from the coil (5 and 10 cm). We found that the SPLs were louder at closer proximity from the coil and directly dependent on the MO. We also found that in all studied conditions, SPLs were lower than the OSHA permissible thresholds for short (<15 min) acoustic exposure, but at extremes of use, may generate sufficient noise to warrant ear protection with prolonged (>8 h) exposure.

Introduction

Repetitive transcranial magnetic stimulation (rTMS) is increasingly used in clinical and experimental applications with two devices presently cleared by the Food and Drug Administration (FDA) for patients with medication-refractory depression [1,2]. Although approved for clinical use, rTMS poses possible adverse side effects, including transient auditory threshold shifts and hearing loss due to acoustic trauma [3–6].

The sound produced by each TMS pulse is a loud click, a broadband acoustic artifact, potentially greater than 120 dB of sound pressure level (SPL), which originates from rapid stimulation coil deformation [6,7]. Without hearing protection, the Occupational Safety and Health Administration (OSHA) restricts the exposure to such impulsive noise if it is >140 dB. Lower intensities (≤140 dB) are also considered risky by OSHA which limits exposure times to 15 min for noise in the 115–140 dB range, and to 8 h for noise in the 90–115 dB range. OSHA recommends hearing protection for all persons exposed to noise in excess of these amplitude and time limits [8].

rTMS device manufacturers are aware of the acoustic trauma risk, and newer coil designs implement changes to minimize acoustic artifacts. However, the magnitude and variability in the acoustic noise generated by commercially-available coils has not been extensively studied. We therefore obtained SPL measures from four common commercial rTMS devices as a step toward informed standardization of precautions related to rTMS-induced acoustic noise.

Materials and methods

We tested four stimulators with their respective rTMS coils: Magstim Rapid[2] (Magstim, Wales, UK) and D70 alpha, MagPro X100 (MagVenture, Farum, Denmark) and a liquid-cooled Cool Coil B-65, the NeuroStar TMS Therapy System and standard coil (Neuronetics

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Table 1
Individual mean (±SD) SPLs associated with TMS devices (in dB).

Protocol	5 Hz, 5 cm from coil			5 Hz, 10 cm from coil		
MO	60%	80%	100%	60%	80%	100%
Magstim[a]	83.04 ± 0.25	89.88 ± 0.18	94.16 ± 0.25	79.56 ± 0.11	87.14 ± 0.15	90.20 ± 0.67
MagPro[b]	75.50 ± 0.35	77.44 ± 0.15	79.38 ± 0.18	72.80 ± 0.07	75.46 ± 0.13	78.32 ± 0.18
Neurostar[c]	81.50 ± 0.16	83.22 ± 0.13	83.56 ± 0.21	79.44 ± 0.09	81.82 ± 0.13	82.74 ± 0.09
Brainsway[d]	86.38 ± 0.29	90.00 ± 0.22	92.38 ± 0.15	75.62 ± 0.08	80.74 ± 0.79	83.32 ± 0.08
Protocol	10 Hz, 5 cm from coil			10 Hz, 10 cm from coil		
MO	60%	80%	100%	60%	80%	100%
Magstim[a]	86.76 ± 0.11	92.14 ± 0.30	94.70 ± 0.10	83.32 ± 0.19	89.26 ± 0.18	92.18 ± 0.13
MagPro[b]	77.54 ± 0.11	80.64 ± 0.23	83.22 ± 0.16	75.44 ± 0.09	78.42 ± 0.16	80.60 ± 0.16
Neurostar[c]	84.18 ± 0.13	91.52 ± 0.13	93.48 ± 0.25	82.46 ± 0.21	83.44 ± 0.15	90.72 ± 0.18
Brainsway[d]	88.30 ± 0.19	92.22 ± 0.16	96.36 ± 0.13	77.14 ± 0.19	81.60 ± 0.14	86.34 ± 0.63

[a] Magstim Rapid^2 with D70 alpha coil.
[b] MagPro X100 with a cool coil B-65.
[c] NeuroStar TMS therapy system.
[d] Brainsway deep TMS with H coil.

Inc, PA, USA) and Brainsway Deep rTMS H System and standard coil (Brainsway, Jerusalem, Israel). Each was programmed to deliver an rTMS protocol while we recorded the SPLs. The MagStim and MagPro were tested with figure-eight coils, while the Neurostar was evaluated with the iron-core coil, and the Brainsway was tested with a helmet-based H-coil.

We measured the acoustic artifacts produced by the stimulation coils with a digital sound level meter (Model 407750; Extech Instruments, MA, USA) programmed with an A weighting and a response time of 1 s, simulating the frequency response of the human ear. The sound meter was held orthogonal to the coil plane 5 cm from the center of the TMS coils. rTMS protocols at 5 and 10 Hz with 3 s train durations were employed at 60, 80, and 100% machine output (MO). The same procedure was repeated by positioning the sound meter 10 cm from the coil. Each protocol was repeated for 5 consecutive trials and we report the maximum as well as mean SPL (Table 1). We limited ourselves to these parameters after performing preliminary runs with longer train durations. In case of the Brainsway deep TMS system wherein the coil is enclosed in a helmet, the sound meter was held inside the helmet on the contralateral side of the active magnet at a distance of 5 cm. To approximate the 10 cm distance, the sound meter was positioned

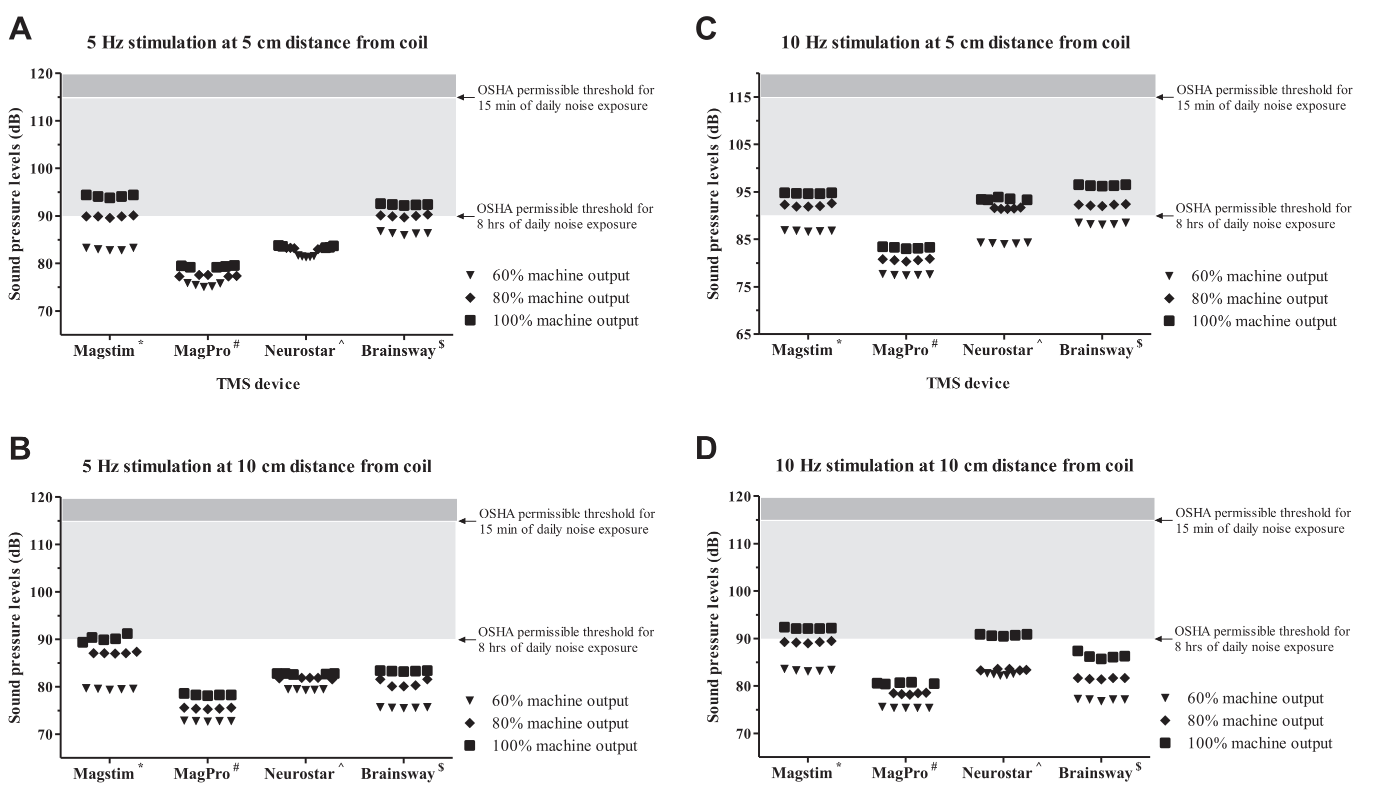

Figure 1. Measurements of sound pressure levels (SPLs) of acoustic artifacts produced by the Magstim, MagPro, Neurostar and Brainsway TMS coils. The scatter plot shows five trials of SPLs recorded at 60, 80 and 100% machine output for a 3 s train duration (A) in a 5 Hz rTMS session with the sound meter positioned 5 cm away from the face of the coil; (B) in a 5 Hz rTMS session with the sound meter positioned 10 cm away from the face of the coil; (C) in a 10 Hz rTMS session with the sound meter positioned 5 cm away from the face of the coil; (D) in a 10 Hz rTMS session with the sound meter positioned 10 cm away from the face of the coil. The light gray solid box between 90 dB and 115 dB marks the Occupational Safety and Health Administration (OSHA) permissible thresholds for exposures of 8 h per day and 15 min per day, respectively, before protection against the effects of noise exposure shall be provided. *Magstim Rapid^2 with D70 alpha coil, #MagPro X100 with a cool coil B-65, ^NeuroStar TMS Therapy System, $Brainsway deep TMS with H coil.

against the outer surface of the helmet. To control for ambient noise, all recordings were performed in the same room.

Results

With the sound meter 5 cm from the coil surface during a 5 Hz rTMS protocol, the Magstim coil generated the greatest peak SPL of 94.4 dB at 100% MO. Similarly, the MagPro, Neurostar and Brainsway coils, at 100% MO produced maximum SPLs of 79.6 dB, 83.8 dB and 92.6 dB, respectively. Figure 1A plots the individual peak SPLs from five consecutive trials, for the four TMS coils. After moving the sound meter to 10 cm from coil, the maximum SPLs recorded at 100% MO for Magstim, MagPro, Neurostar and Brainsway were 91.2 dB, 78.6 dB, 82.8 dB and 83.4 dB, respectively. Individual SPLs as a function of intensity are shown in Figure 1B. As expected, the sound levels increased with higher MO and closer proximity to the coil. MagPro and Neurostar devices produced the lowest acoustic output (<90 dB) at both 5 and 10 cm distances.

To test a potentially louder protocol, we also measured the acoustic artifact during a high-frequency, 10 Hz, rTMS train. With increasing stimulation intensity, the proportional SPL increase is shown in Figure 1C. The maximum SPLs recorded at 100% MO were 94.8 dB, 83.4 dB, 93.9 dB and 96.5 dB for Magstim, MagPro, Neurostar and Brainsway coils, respectively. Similar to the 5 Hz protocol, the peak SPLs dipped at 10 cm distance relative to 5 cm. In this case, 92.4 dB (Magstim), 80.8 dB (MagPro), 90.9 dB (Neurostar) and 87.4 dB (Brainsway) were the loudest intensities at 100% MO (Figure 1D). With 10 Hz rTMS at both 5 and 10 cm distances, only the MagPro coil generated SPLs lower than the 90 dB OSHA threshold for 8 h exposure. Table 1 lists the mean ± SD of SPLs generated by all four coils.

Discussion

Typical therapeutic rTMS sessions last 20–60 min. Since the acoustic artifacts produced by all tested coils were lower than the permissible 115 dB threshold for such short exposure, a single rTMS session likely poses minimal risk to patients.

In realistic scenarios, rTMS operators are unlikely to experience 8 h of continuous rTMS, and are likely to be more than 10 cm away from the stimulating coil. Yet, at high MOs, the rTMS-related acoustic artifact may cross the 90 dB OSHA threshold, and hearing protection for rTMS operators working in 8 h shifts should be considered (and is provided routinely in our laboratory).

We note that the present study was limited to four stimulator-coil combinations. Since the amplitude of rTMS noise is dependent on coil design, analogous testing will be useful in individual laboratories. Another limitation of this study is the absence of human or animal physiologic markers of acoustic injury. However, such work is beyond the scope of the present short report.

We anticipate that these data can facilitate the design of laboratory safety guidelines and the drafting of IRB applications or text for informed consent, as well as the selection and design of rTMS devices.

References

[1] www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfpmn/pmn.cfm?ID=K061053.

[2] www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfPMN/pmn.cfm?ID=K122288.

[3] Pascual-Leone A, Cohen LG, Shotland LI, et al. No evidence of hearing loss in humans due to transcranial magnetic stimulation. Neurology 1992;42:647–51.

[4] Zangen A, Roth Y, Voller B, Hallett M. Transcranial magnetic stimulation of deep brain regions: evidence for efficacy of the H-coil. Clin Neurophysiol 2005;116:775–9.

[5] Rossi S, Hallett M, Rossini PM, Pascual-Leone A, Safety of TMS Consensus Group. Safety, ethical considerations, and application guidelines for the use of transcranial magnetic stimulation in clinical practice and research. Clin Neurophysiol 2009;120(12):2008–39.

[6] Tringali S, Perrot X, Collet L, Moulin A. Repetitive transcranial magnetic stimulation: hearing safety considerations. Brain Stimul 2012 Jul;5(3):354–63.

[7] Counter SA, Borg E. Analysis of the coil generated impulse noise in extracranial magnetic stimulation. Electroencephalogr Clin Neurophysiol 1992 Aug;85(4):280–8.

[8] www.osha.gov.